

INVESTIGATING SPEED PATTERNS AND ESTIMATING SPEED ON TRAFFIC-CALMED STREETS

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ABSTRACT

Previous research has shown that speed reduction on residential streets can be attained through traffic calming. This research examines the speed profiles of individual vehicles on traffic-calmed streets, in order to provide a better understanding of how drivers react to calming devices over an extended street length and to find ways of estimating speeds along traffic-calmed streets.

Results indicate that traffic-calmed streets do not necessarily promote low speed environments. It was found that 85th percentile speeds at long distances from calming devices were 45-55 km/h for horizontally deflected streets and 40-45 km/h for vertically deflected streets. The speed hump and the angled slow point produced the biggest speed reductions, with the 2-way mid-block narrowings causing no significant speed changes.

Smaller variations in speeds were recorded on the speed hump and the raised angled slow point, while the speed table registered a higher variation. This suggests that drivers have different perceptions of appropriate operating speeds. For multiple devices, larger spacing produced higher speeds between devices.

These findings, along with speed difference curves and speed-spacing models developed from this research, can aid in the selection of device type and spacing between devices in order to improve the effectiveness of traffic calming.

1 INTRODUCTION

Traffic calming is a speed management technique that relies on the concept of using physical and visual devices to persuade motorists to slow down. The devices used for traffic calming can be divided into two broad categories: vertical deflections and horizontal deflections. Vertical deflections are raised segments that force drivers to slow down in order to minimise unpleasant bumping or vibrating sensations. Horizontal deflections are either lateral shifts in the roadway that create non-linear driving paths, or constrictions of the roadway that cause drivers to lower their speeds in order to manoeuvre safely through the deflection.

There is ample evidence that attests to this mostly advantageous speed management technique, such as the findings that reductions in speed of up to 23% were achieved through various traffic calming measures in the United States (Ewing, 1999) and that an average reduction in 85th percentile speed of 16 km/h was attained from a survey of 35 traffic calming schemes in Britain (Hass-Klau, et al., 1992).

When a street is subjected to traffic calming, the “zone of influence” (i.e. that part of the street where speeds are lower due to the calming device) does not typically encompass the entire street. Slow points were found to have influence zones of 80 m in total (Taylor and Rutherford, 1986). Low speeds (< 30 km/h) as a result of speed-reducing effect brought about by traffic calming, are normally achieved within this zone, where drivers are forced to decelerate upon reaching the device. Outside the zone of influence, drivers have the freedom to operate at their desired speeds, some reaching speeds over the speed limit (> 50 km/h).

This means that there is a higher chance of speeds on residential streets exceeding 50 km/h if the zone of influence is small and the spacing of the devices is large. The type of device, the use of multiple devices and spacing between devices are factors that dictate the spread of the influence zone. The human factor also plays a role in determining the extent of the influence zone as different drivers react differently to the devices.

The first part of this paper presents an investigation into the speed patterns on traffic-calmed streets, to provide some knowledge on how drivers react to different traffic calming devices and to what extent these devices exert a speed-reducing effect. The second part details how speed observations may be used to estimate speed on traffic-calmed streets, and to relate speed midway between devices with spacing of multiple devices.

1.1 Objectives

The objectives of this ongoing study are:

1. To determine the speed-reducing effect and the extent of influence zones of vertical and horizontal deflections.
2. To examine the effect of traffic calming devices on speed variation.
3. To develop speed estimation curves and speed-spacing models for the prediction of speed on traffic-calmed streets.

1.2 Background

Speeding in residential areas can be partly attributed to a driver's perception of safe speed. For roads with lower speed limits, drivers' perceptions of safe speed are commonly higher than the legal speed, despite drivers being aware of the speed limit (Shinar, 2001).

The general speed limit of 50 km/h for urban traffic areas including residential precincts seems high for local streets, considering that these streets do not serve high traffic volumes or speeds, and are accorded the lowest design standard. The primary function of local streets is to provide access to homes to those who enter or leave, and those who deliver and collect. These streets are shared spaces where motorists co-exist with pedestrians, cyclists and other active road users.

The risk of adult pedestrians dying as a result of being hit by the front of cars moving at 50 km/h is twice as high as the risk at 40 km/h and more than five times higher than the risk at 30 km/h (Rosen and Sander, 2009). Thus, it is more appropriate for vehicle speeds in such an environment to be between 30-40 km/h rather than to reach as high as 50 km/h.

While it is legally allowable to travel at speeds close to 50 km/h on most local streets, it is not encouraged from a safety point of view. Higher speeds increase accident frequency and severity. Taylor et al. (2000) concluded that a 10% increase in mean speed would result in a 21% increase in the number of accidents. The risk of being involved in an injury crash also rises as speed increases. Kloeden et al. (2001) found that the risk of involvement in casualty accidents is doubled for every 5 km/h increase in speed. For locations with speed levels of 50 km/h, a 1 km/h increase in speed could result in a 4.0% increase in injury accidents, a 6.1% increase in serious injury accidents and an 8.2% increase in fatal accidents (ERSO, 2007).

1.3 Speed, Safety and the Driver

Speed is fundamentally associated with road safety. Speed has been found to be a major causative factor in about 10% of all accidents and 30% of fatal accidents (TRB, 1998). In New Zealand, speeding was a factor in 30% of fatal crashes, 20% of serious injury crashes and 15% of minor injury crashes for the years 2007 to 2009 (NZ MoT, 2010).

Stopping sight distance increases with speed, which means there is a smaller possibility of avoiding a collision if a vehicle moving at a higher speed encounters an obstacle in its path head-on. Speed is also linked to the reduction of visual ability while driving. As the vehicle moves at greater speeds the visual field of a driver gets narrower, hence reducing the capability of the driver to assess potential hazards and react in time when an obstacle appears from either side of this reduced field of view. Furthermore, higher speed alters depth perception by making it more difficult for a driver to gauge distances to objects in front of them.

Drivers are influenced by an array of internal and external factors when they drive their vehicles on the road. The World Health Organisation (2004) lists a total of 32 variables that are believed to affect a driver's choice of speed. These variables represent three main contributory factors: road and vehicle factors, traffic and environment factors, and driver related factors.

Shinar (2007) explains that our choice of speed is governed by who we are (individual differences) and what we want (motivational factors). Age, gender, education and income have diverse effects on speed choice. Men are more likely to speed than women (Jonah et

al., 2001) and younger drivers are more likely to speed than older drivers (Horberry et al., 2004). Interestingly, drivers with higher education and income are more likely to exceed speed limits (Shinar et al., 2001).

2 RESEARCH METHOD

2.1 Site Selection and Data Collection

The study involved speed data collection on 17 residential streets in Christchurch, New Zealand that have been subjected to traffic calming, mainly through the use of speed humps, speed tables, angled slow points and mid-block narrowings. These streets have been classified as low volume roads with average daily traffic less than 500 vehicles. Seven streets had single devices and the remaining ten streets had multiple devices. All sites were through streets with on-street parking provision. Street widths ranged from 8.0 m to 13.5 m.

The Watts profile speed humps were 100 mm in height and ranged from 3.6 m to 3.8 m in length. The speed tables were 120 mm (for the single device) and 75 mm (multiple devices) in height, while the lengths ranged from 3.6 m to 5.0 m, with 1:8 (single device) and 1:12 (multiple devices) ramp gradients.

Speed data were obtained using a ProLaser III light detection and ranging (LIDAR) meter. The reason for choosing a manual collection method instead of an automatic one was principally to acquire longitudinal speed profiles of individual vehicles. This would enable investigation of the variations between drivers in terms of speed choice and their response to devices.

Data were collected during weekday off-peak periods for the purpose of obtaining speeds of vehicles unimpeded by motorised and non-motorised traffic. Sample sizes ranged between 100 and 200 drivers per site. To minimise the effect of parked vehicles, streets with effective widths wide enough to allow opposing vehicles to pass each other without the need to slow down or stop were selected. All data were collected under clear and dry conditions for the purpose of eliminating factors that affect driving, such as lack of visibility and wet road surfaces.

To rule out the effect an observer might have on speed choice, observations were made from a vehicle parked by the side of the road, therefore concealing the observer from the view of drivers. The positioning of the vehicle was also chosen so as not to impede traffic.

2.2 Analytical Methods

Speed Profiling

85th percentile speed and mean speed profiles were plotted to compare the speed-reducing effect for each type of traffic calming device. A typical speed profile using 85th percentile speeds at varying distances of a traffic-calmed street is shown in Figure 1, together with some of the terminology used in this paper.

The profiles provided a better understanding of how drivers react to vertical and horizontal shifts. Furthermore, speeds at distances away from the devices and between devices were able to be studied. Influence zones generated by calming devices were also obtained from the speed profiles.

Tests for Homogeneity of Speed

Deviations from the mean speed when traversing calming devices signify behavioural differences among drivers. A plot of standard deviations at distances along a calmed-street gave a general idea of these differences. The F-test for equality of variances was employed, to test the statistical significance of differences in the standard deviation in speed between impeded segments (i.e. at the device) and unimpeded segments (i.e. at distances away from the device), to determine the changes in speed variations caused by calming devices.

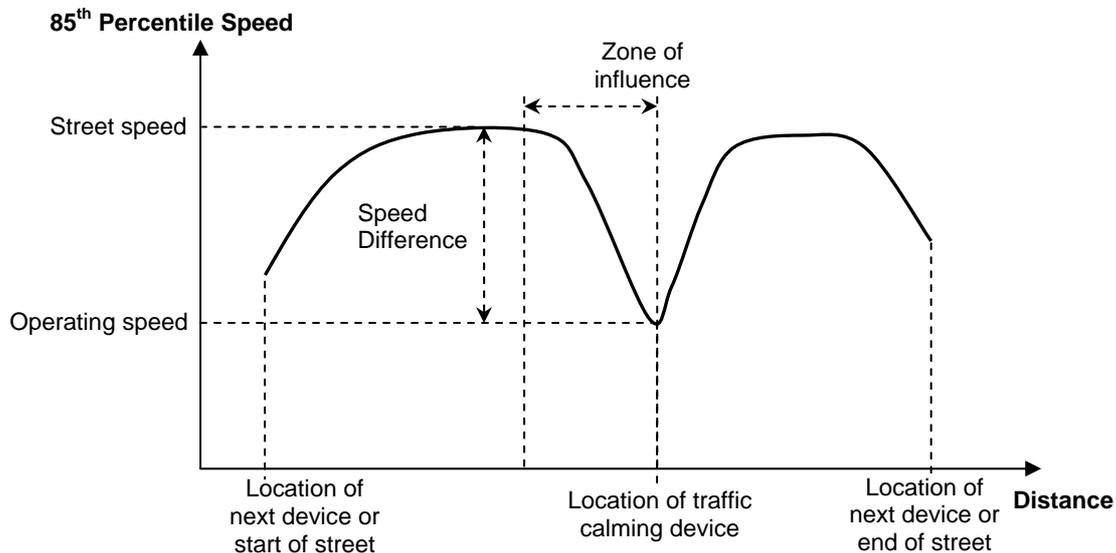


Figure 1: Typical speed profile of a traffic-calmed street

Speed Modelling

Plots of 85th percentile and mean speeds at distances along calmed-streets indicated that the speed-distance relationships that exist between starting/ending points on the street and the device and between two devices were approximately quadratic in form. Speed models were developed for predicting speed at varying distances from the devices. Models for estimating speed midway between speed humps and speed tables were developed using simple linear regression analysis. The speed-spacing models were tested for significance using the F-test for the regression model and the t-test for the regression coefficient.

3 RESULTS

The speed profiles produced for the case studies listed below were found to have similar patterns to other locations with the same device type and are therefore suitably representative. The following sub-sections detail the results of analyses conducted on the speed profiles.

3.1 Speed-Reducing Effect and Zones of Influence

3.1.1 Device Operating Speed

The operating speed of a traffic calming device was taken as the 85th percentile speed recorded at the device. The operating speed serves as an indicator of the effectiveness of calming devices. An effective device will have an operating speed close to or smaller than

the target speed. The target speed for vehicles crossing these traffic calming devices is 20 km/h, as indicated by advisory signs. The highest 85th percentile speed observed along the street (mainly on sections not impeded by traffic calming devices) was fixed as the street speed. Table 1 shows the device operating speed for the types of devices covered in the seven case studies.

While the speed hump came close to attaining the target speed, the other devices did not exhibit a similar effect. Interestingly, the speed table did not perform as well as expected, despite the table being 20 mm higher than the hump. This was probably due to the extensive flat top and ramps on both ends, which provided a smoother ride compared to the speed hump.

The operating speeds of flush mid-block narrowings were considerably higher than other devices and close to the travelling speeds on unimpeded segments of the streets, which indicates that these devices are ineffective.

One-lane angled slow points performed better than mid-block narrowings, in terms of lowering speeds. The raised angled slow point registered a lower operating speed, which was even lower than what the speed table produced.

Table 1: Operating speeds, street speeds and zone of influence for single traffic calming devices

Device	Location	Operating Speed (km/h)	Street Speed (km/h)	Speed Difference (km/h)	Zone of influence (m)
Speed hump 100 mm (H), 3.7 m (L), 5.8 m (W)	Burke Street, Addington	21.9	43.0	21.1	50
Speed table 120 mm (H), 5.8 m (L), 8.3 m (W) 1:8 ramp gradient	Randolph Street, Woolston	35.0	46.1	11.1	55
Angled slow point One-lane, flush 3.0 m (W), 5.1 m (L)	Mackenzie Avenue, Woolston	39.5	54.5	15.0	110
Angled slow point One-lane, raised 3.2 m (W), 16.0 m (L), 50 mm (H) 1:20 ramp gradient	Rattray Street, Riccarton	30.0	49.9	19.9	110
Mid-block narrowing One-lane, flush 3.6 m (W), 11.6 m (L)	Stratford Street, Fendalton	50.8	53.4	2.6	44
Mid-block narrowing One-lane, raised 4.6 m (W), 3.0 m (L), 50 mm (H) 1:40 ramp gradient	Kirkwood Avenue, Ilam	44.7	48.2	3.5	40
Mid-block narrowing Two-lane, flush 5.6 m (W), 6.0 m (L)	Hamilton Avenue, Ilam	50.8	52.1	1.3	40

3.1.2 Speed Difference

The difference between the street speed and operating speed was used to represent the speed-reducing effect of traffic calming devices.

Of the seven devices studied the speed hump was most effective, reducing speed by 21.1 km/h. The least effective device was the two-lane mid-block narrowing, which registered the lowest speed difference of 1.3 km/h (refer to Table 1).

Overall, mid-block narrowings performed poorly. Not only were the speeds at these devices high (44.7 to 50.8 km/h), but the changes in speeds were the least (1.3 to 3.5 km/h).

The raised one-lane angled slow point was the most effective horizontal deflection. It even performed better than the speed table, in terms of lowering speeds from the unimpeded segment to the device. The element of vertical deflection introduced to the lateral deflection probably contributed greatly to the effectiveness of this device.

Vertical deflections appear to be more advantageous in maintaining speeds below 50 km/h throughout the entire length of a street. The same however, cannot be said of horizontal deflections. 85th percentile speeds on unimpeded segments were mostly in excess of 50 km/h. This may reflect the ability of drivers to align their approach to horizontal devices to minimise the speed reduction.

The difference between mean speeds at the device and at the distance producing the peak mean speed for each device are given in Table 2. The differences in mean speed were higher than the 85th percentile speed differences for the speed table and the one-lane raised mid-block narrowing. When tested for significance using the t-test, the differences for the flush mid-block narrowings were not significant.

Table 2: Mean speed differences and t-test results for significance

Device	Mean Speed at Device (km/h)	Peak Mean Speed (km/h)	Speed Difference (km/h)	t-Test for Significance
Speed hump	17.6	36.8	19.2	Significant ($p < 0.05$)
Speed table	24.5	40.4	15.9	Significant ($p < 0.05$)
Angled slow point <i>One-lane, flush</i>	33.5	47.3	13.8	Significant ($p < 0.05$)
Angled slow point <i>One-lane, raised</i>	23.3	42.2	18.9	Significant ($p < 0.05$)
Mid-block narrowing <i>One-lane, flush</i>	44.2	46.5	2.3	Not Significant ($p > 0.05$)
Mid-block narrowing <i>One-lane, raised</i>	34.4	40.8	6.4	Significant ($p < 0.05$)
Mid-block narrowing <i>Two-lane, flush</i>	43.5	44.8	1.3	Not Significant ($p > 0.05$)

It should be noted that the length of the unimpeded segment affects speed between devices. A longer unimpeded segment will allow vehicles to attain higher speeds. Therefore, the placement of calming devices should be such that there is insufficient length for drivers to reach high speeds. This will be further discussed in section 3.4.

3.1.3 Zone of Influence

The zone of influence is the area over which a traffic calming device produces a speed-reducing effect. For isolated traffic calming devices, the total zone of influence is the sum of the influence zones for the particular direction of travel.

Angled slow points exerted the most extensive zones of influence. Drivers began reducing their speeds at 100-110 metres from the device. This was probably due to the appearance of the device, which from a distance resembles as mid-block closure.

Drivers approaching vertical deflections started to reduce their speeds at 50-55 metres from the device. This was quite substantial, given that the longitudinal length of vertical deflection is 3.7 metres for the speed hump and 5.8 metres for the speed table. In comparison, angled slow points are up to 16.0 metres in length.

For mid-block narrowings, the speed-reducing effect was registered at distances 40-44 metres from the device. However, due to the minuscule reduction in speed, the zones of influence generated by flush mid-block narrowings are not noteworthy.

3.2 Variation of Speed

For the seven case studies, the standard deviation in speeds recorded at impeded and unimpeded sections on the streets were all below 10 km/h, except for the street with a raised mid-block narrowing, where a deviation of 11.5 km/h was recorded at the device.

From standard deviation plots, it was noticeable that deviations at the speed table and the raised mid-block narrowing were higher than on unimpeded sections. All other devices showed deviations approximately the same or lower than deviations on the unimpeded sections (see Figure 2).

To obtain statistical significance for the variation of speed between impeded and unimpeded sections, F-tests for the equality (or inequality) of variances were employed. There was some evidence to suggest that the variance in speed at the speed hump was significantly lower than the variances on unimpeded sections. This shows that, for this device, most drivers lower their speeds to meet the target speed of 20 km/h – an action influenced by the “less apologetic design of speed humps, which considerably impairs riding comfort when traversed at high speeds.

For one-lane angled slow points, the results were contrasting. The raised angled slow point had an effect similar to the speed hump. The flush variant, however, did not yield any significant differences in speed variance. This suggests that combining a platform to the deflected path is more effective in closing the range of vehicle speeds, but not necessarily lowering speeds to meet the target speed.

Interestingly, the speed table had the opposite effect. Variances in speed at distances 20 m or more from the speed table were significantly smaller than the variance at the device. This shows that drivers are divided when it comes to deciding on their crossing speeds. The large gap between maximum and minimum speeds recorded at the speed table is testimony to the inconsistency of driver behaviour when it comes to reducing speeds at this particular device. The “more apologetic” design of speed tables, which allow better riding comfort as opposed to speed humps, is perhaps the major reason why some drivers maintain their speeds even when crossing speed tables.

The mid-block narrowings had equal variances in speed at the devices and on unimpeded segments. This was expected, given that the device operating speeds were about the same as the street speeds, which suggested that drivers were not affected by the constriction of the roadway and chose to maintain their speeds along the streets.

Table 3 summarises the outcomes of the F-test for equality of variances in speed conducted for the seven traffic calming devices.

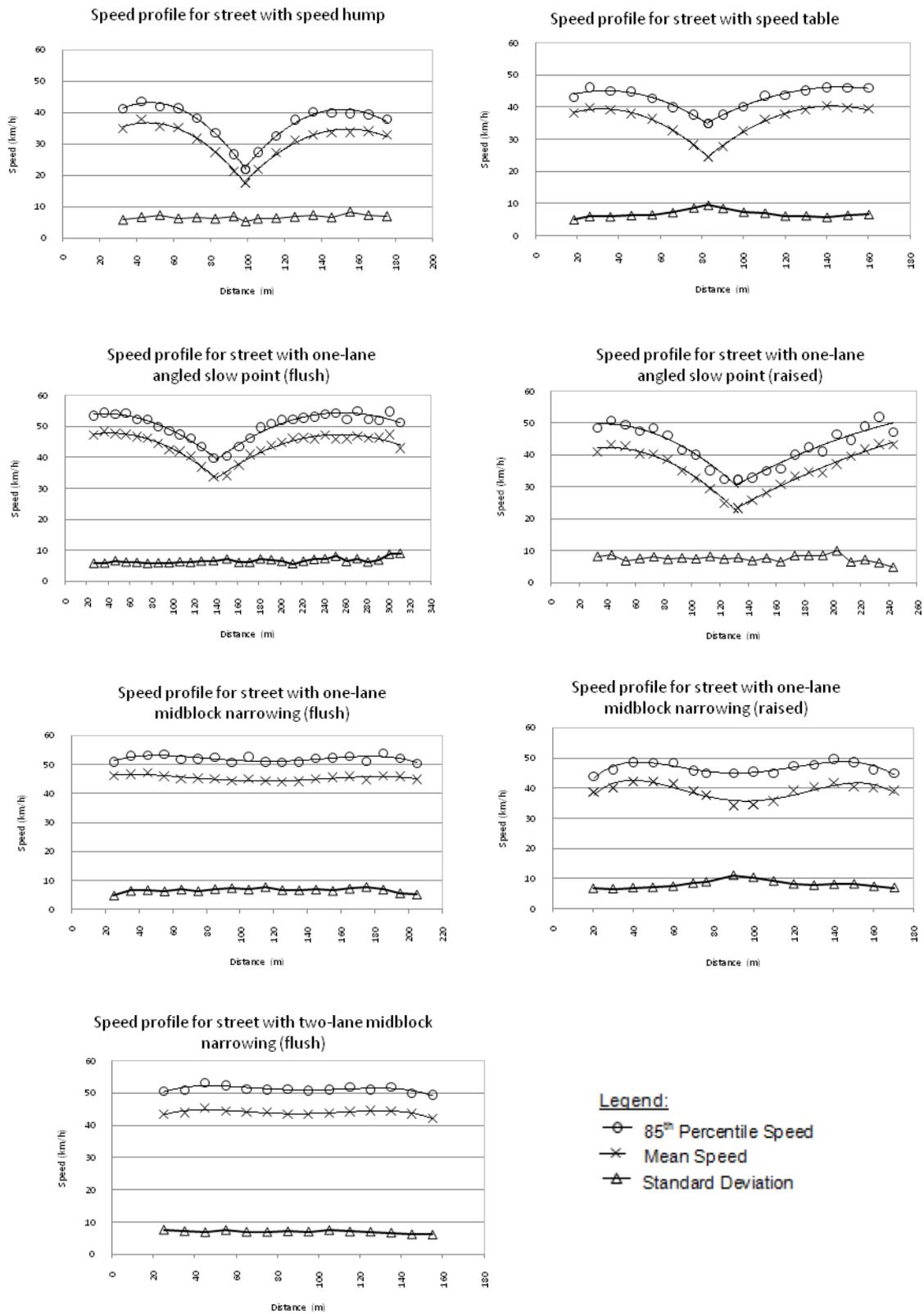


Figure 2: Speed profiles and standard deviation plots

Table 3: F-test results for equality of variances in speed for single traffic calming devices

Device	Distance To The Device (m)									
	10	20	30	40	50	60	70	80	90	100
Speed Hump	+	=	+	+	+					
Speed Table	=	-	-	-	-					
Angled slow point (One-lane, raised)	+	+	+	+	=	=	+	+	+	+
Angled slow point (One-lane, flush)	=	=	=	=	=	+	=	=	=	=
Mid-block narrowing (One-lane, raised)	=	=	=	=	=					
Mid-block narrowing (One-lane, flush)	=	=	=	=	=					
Mid-block narrowing (Two-lane, flush)	=	=	=	=						

Key: +/-/= denotes larger/smaller/equal variance in speed, compared to variance at device

3.3 Speed Estimation

3.3.1 Speed Difference Curves

85th percentile speeds within the influence zones of streets calmed by single devices can be estimated using the speed difference curves established from the case studies, as shown in Figure 3. The coefficients of determination (R^2) for the curves were significantly higher than zero (between 0.9721 and 1.0000), which reflects the high accuracy of the models.

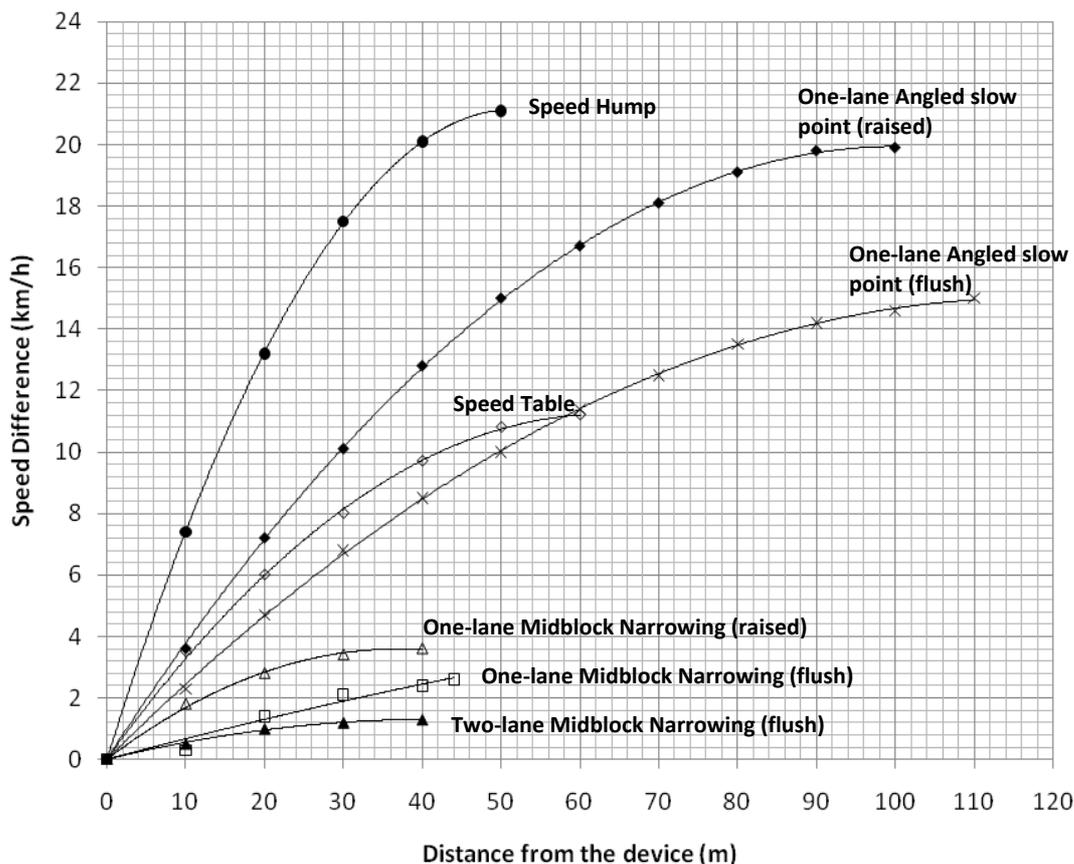


Figure 3: Speed difference curves for traffic calmed streets

Each curve represents the difference in 85th percentile speeds between a point within the influence zone and the device. The beginning of the curve denotes the location of the device, while the end of the curve denotes the location where the influence zone comes into effect, i.e. the point where drivers start reducing their speeds (see Figure 3).

The approach length, i.e. the distance between the device and the next device or street entry, influences the street speed. Short approaches produce lower street speeds. Therefore, a smaller speed difference will be expected for short approaches.

3.4 Speed-Spacing Models

The relationship between speed and spacing between calming devices was best explained through linear regression modelling. Eight pairs of speed humps and nine pairs of speed tables were studied to derive equations that could be used to predict the 85th percentile (V_{85}) and mean speeds (V_{mean}) midway between these devices. The average device operating speed was set as the intercept, where spacing is effectively zero. All streets had the 50 km/h speed limit.

Figures 4 and 5 show the regression lines and equations established for speed humps and speed tables respectively. The regression models and coefficients showed high significance ($p < 0.05$) when tested using the F-test and t-test respectively. The high R^2 values obtained for the regression lines showed that a high proportion of the variation can be explained by the regression relationships.

It is evident that midway speeds increase as more space is provided between devices. The speed-spacing model indicates that the 85th percentile speed will likely exceed 50 km/h when the spacing between two speed humps (s_h) is 170 m or more. Therefore, to prevent speeding between devices, it is best to keep spacing at 165 m or less. If a speed environment (i.e. a street having a speed level characterised by the 85th percentile speed) of 40 km/h is desired, then a spacing of 85 m or less is recommended.

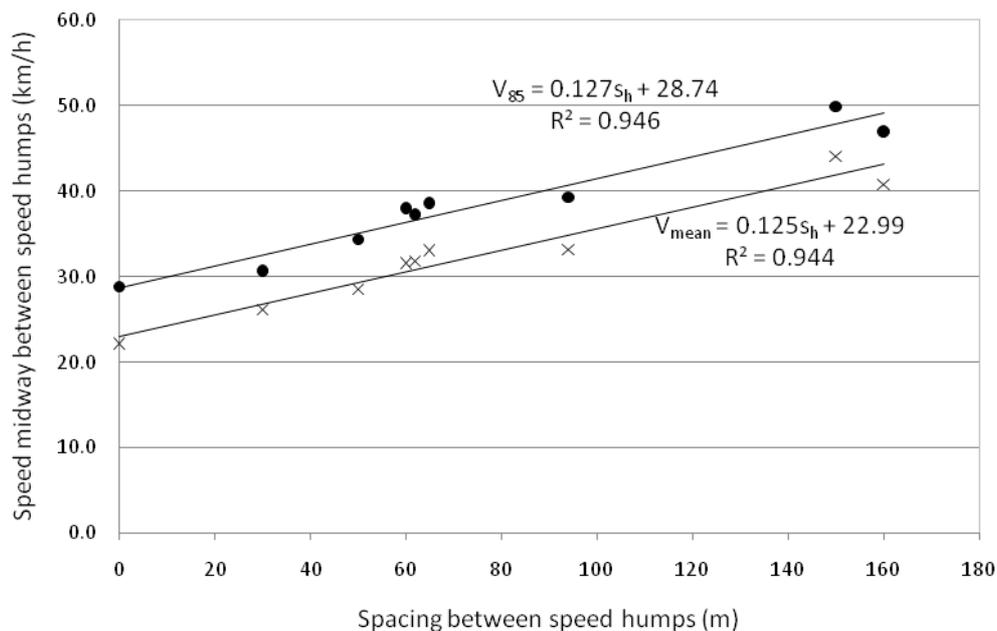


Figure 4: Speed-spacing model for speed humps

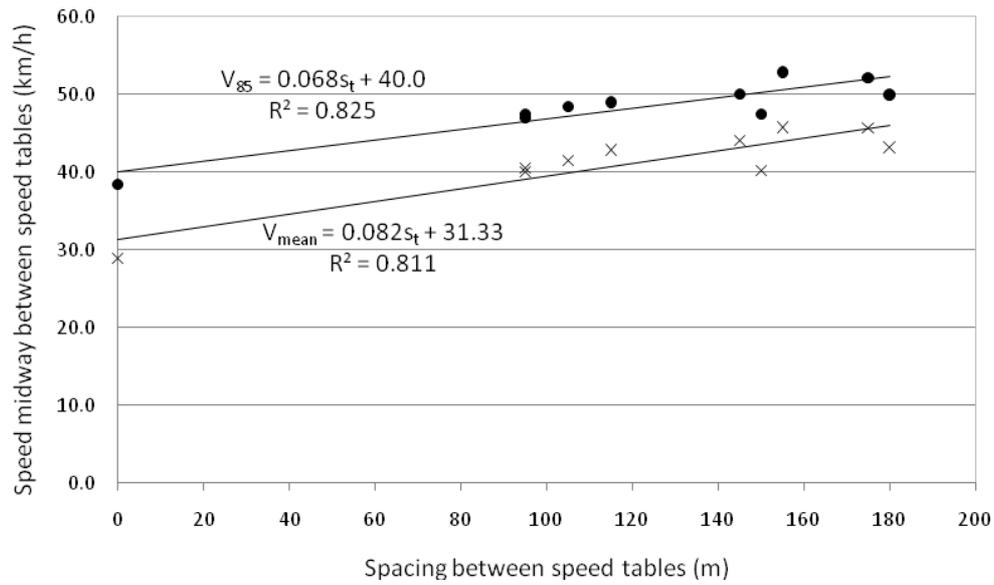


Figure 5: Speed-spacing model for speed tables

While it may not be possible to have 40 km/h speed environments on roads calmed by multiple speed tables, a speed environment of 45 km/h can be achieved if the spacing between speed tables (s_t) is 70 m or less. Spacing in excess of 145 m will result in more vehicles surpassing 50 km/h.

To maintain mean speeds below 50 km/h, spacings should not exceed 215 m and 225 m for speed humps and speed tables respectively. Table 3 shows recommended spacings for attaining desired maximum street speeds.

Table 3: Recommended spacings based on speed-spacing models

Desired max. street speed (km/h)	85 th Percentile Speed				Mean Speed				
	35	40	45	50	30	35	40	45	50
Speed humps	≤ 50	≤ 85	≤ 125	≤ 165	≤ 55	≤ 95	≤ 135	≤ 175	≤ 215
Speed tables	*	*	≤ 70	≤ 145	*	≤ 45	≤ 105	≤ 165	≤ 225

* Desired maximum street speed not attainable

These speed-spacing models are also applicable for the placing of speed humps or speed tables at appropriate distances from junctions.

4 CONCLUSIONS

The following conclusions were drawn from this study:

- (a) Speed humps produce the lowest operating speed and one that is close to the target speed of 20 km/h. These devices are also most influential in reducing street speed, as proven by the sizeable speed change and small dispersion of speeds.
- (b) Speed tables do not perform as well as speed humps. Though street speeds are kept below the limit, operating speeds are approximately 13 km/h higher than speed humps. The gentler design of the observed speed tables enables drivers to operate their vehicles at higher speeds, and some do, leading to a higher standard deviation in speed at the device than at speed humps.
- (c) One-lane raised angled slow points produce a greater speed-reducing effect than speed tables and just like the speed hump, the deviations in speed are smaller than on other sections of the street. However, street speeds are still fairly high.
- (d) Mid-block narrowings are not effective in reducing speeds. The differences between operating speeds and street speeds are slight.
- (e) Angled slow points exert the most extensive zones of influence, meaning that drivers begin reducing speeds at a further distance from the device. By contrast, drivers choose to slow down at a closer distance to mid-block narrowings.
- (f) Spacings between speed humps of 170 m or more will likely result in 85th percentile speeds exceeding 50 km/h. For speed tables, the equivalent spacing is 145 m and above.
- (g) Spacings of 85 m or less is recommended for speed humps if a speed environment of 40 km/h is desired. Spacings between speed tables of 70 m or less will likely result in speed environments of not more than 45 km/h.

This study has provided some insight into the effects of traffic calming devices on driver behaviour via their choice of speed not only when traversing the devices but also as they move towards and away from the devices. While speeds may be lowered at some of the devices, street speeds may still be high. This suggests that low speed environments may not be achieved throughout a street unless devices that produce an optimal speed-reducing effect are selected and located at appropriate spacings.

However, engineering solutions alone are often not enough to control speeds in neighbourhoods. There is a better chance of achieving low speed environments on neighbourhood streets if a 30 km/h or 40 km/h speed limit is imposed on local streets and supported by the use of traffic calming devices.

It is therefore recommended that before-after studies on 30 km/h and 40 km/h speed zones on residential streets with and without traffic calming be conducted to gauge the level of effectiveness of these speed management options.

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